BROOKHAVEN NATIONAL LABORATORY
PROPOSAL INFORMATION QUESTIONNAIRE
LABORATORY DIRECTED RESEARCH AND DEVELOPMENT PROGRAM

PRINCIPAL INVESTIGATOR	**Raju Venugopalan (BNL)**	**PHONE**	**ext. 2341**
DEPARTMENT/DIVISION	**Physics/PO**	**DATE**	**04/2009**
OTHER INVESTIGATORS	**Adrian Dumitru (Baruch & RBRC), Jamal Jalilian-Marian (Baruch), Anna Stasto (Penn State & RBRC), Thomas Ullrich (BNL)**		

TITLE OF PROPOSAL	**Exploring signatures of saturation and universality in e+A collisions at eRHIC**
PROPOSAL TERM (month/year)	From **10/09** Through **09/11**

PROPOSAL

Background and Motivation for Project:

A powerful motivation for an e+A collider is to study the properties of gluonic matter in nuclei at high parton density. A remarkable prediction in QCD is that the stability of matter requires that the occupation number of gluons in nuclear wave functions saturate at a value proportional to the inverse of α_S, the QCD coupling constant. A dimensionful scale $Q_S^A(x)$ separates "soft" modes that are maximally occupied from "hard" modes that are not. This scale grows with energy and with nuclear size—so, for large nuclei, gluon momenta up to GeV scales are saturated. A prediction of the Color Glass Condensate (CGC) approach to saturation is that the bulk of the dynamics of high-energy scattering can be expressed in terms of dimensionless combinations of this scale with the nuclear or hadron size. An illustration of this is the *geometrical scaling* of the structure function data observed at HERA [1]. For reviews, see [2].

A further consequence of saturation is universality. Even though different nuclei can have different saturation scales at a given energy (Q_S^2 proportional to $A^{1/3}$), theoretical models predict that at very high energies, the saturation scales of all nuclei will approach a common value independent of the properties of the nuclei in which the gluons are confined [3]. The properties of matter in this universal regime relate to the fundamental structure of the strong interactions itself—such as, for instance, a novel fixed point for the running of the QCD coupling constant or the Froissart bound for the total cross-section.

What are the signatures of saturation in deep inelastic scattering (DIS) off nuclei and can we extract the saturation scale uniquely from these final states? Which signatures are most sensitive to saturation? Can we anticipate precocious onset of saturation in these final states? Can they be clearly distinguished from alternative descriptions? Can one reliably extract the nuclear dependence, the impact parameter dependence, and the energy dependence of the saturation scale? By varying x and A, can we observe hints of the onset of a universal fixed point—what energy range is optimal? While qualitative answers to these questions exist, we do not at present have reliable quantitative answers to all these relevant questions.

In DIS at high energies, final states can be expressed in terms of multi-parton "Wilson line" correlation functions. The state-of-the-art description of the evolution of these correlation functions with energy is given by the JIMWLK renormalization group (RG) equations.

Numerical solutions of these equations are feasible albeit challenging; one group of researchers has previously tackled the problem [4].

The solutions of the JIMWLK RG equations are also inputs in factorized expressions for multi-gluon production in A+A collisions. They are therefore important for a first principles understanding of thermalization in the Quark-Gluon Plasma, the development of elliptic and radial flow, and jet propagation (parton energy loss) in heavy ion collisions.

Goals and Anticipated results:

The goal of this LDRD project is to identify key signatures of saturation in DIS, understand their sensitivity to multi-gluon correlations, and study the energy, nuclear mass number and impact parameter dependence of these correlations. The technical advance required for quantitative studies is to solve the JIMWLK RG equations for multi-gluon correlators using functional Langevin techniques [5]. This goal is challenging albeit feasible as suggested by the one extant numerical computation [4]. A further challenge is to include running coupling effects in the JIMWLK computations. The JIMWLK equations are "leading log in x" results in QCD. Next-to-leading-log level (NLL) and "resumed" solutions are becoming available for the mean field version of JIMWLK, the Balitsky-Kovchegov (BK) equation [6]. Quantitative study of these NLL equations will also form part of our numerical studies.

Such computations are absolutely essential to a quantitative understanding of the onset of saturation dynamics in various DIS final states. From the theoretical standpoint, these computations should be distinguished from dipole models that incorporate saturation dynamics in a *heuristic* manner.

The anticipated results are as follows:

i) Identify final state signatures (inclusive, semi-inclusive and exclusive) in DIS by sensitivity to two and higher point quark and gluon correlation functions.
ii) Develop numerical functional Langevin techniques for solving the corresponding JIMWLK equations for fixed and running coupling. Investigate possibilities for improved, faster algorithms.
iii) Compare results to NLL level solutions of the BK equation
iv) Investigate geometrical scaling, universality of different final states based on these quantitative results (for light and heavy nuclei). Comparison to other frameworks (for example DGLAP)
v) Application of numerical solutions to p+A and A+A collisions. Global analysis.
vi) Interface with e+A event generators

Requested resources:

Because the project requires extensive numerical work, it requires a dedicated post-doc. The PI has a student who has performed similar if less challenging numerical simulations and foresees the student getting involved and being supported by this project. The post-doc and student would provide the dedicated, full time manpower for this project and would collaborate intensively with the PI and co-investigators. We also request one long-term visitor (6 months) who would work jointly on solutions of RG equations and e+A event generator simulations, helping incorporate the former in the latter. This visitor would be shared with the eA event generator proposal (with Thomas Ullrich). We also request modest funds for a dedicated 1 week workshop bringing together ~ 10 experts on RG equations to discuss strategies for their efficient numerical implementation. A preliminary budget is attached to this proposal.

References:

[1] A. M. Stasto, K. Golec-Biernat and J. Kwiecinski, Phys.Rev.Lett.**86**:596-599, (2001).
[2] E. Iancu and R. Venugopalan, hep-ph/0303204, in QGP3, World Scientific Publishers.
[3] A. H. Mueller, Nucl.Phys.A**724**:223-232,(2003).
[4] Y.V. Kovchegov, J. Kuokkanen, K. Rummukainen and H. Weigert, **arXiv:0812.3238**.
[5] J. P. Blaizot, E. Iancu and H. Weigert, Nucl. Phys. A**713**, 441, (2003).
[6] Y. V. Kovchegov and H. Weigert, Nucl. Phys. A**784**, 188 (2007); I. Balitsky and G. A. Chirilli, Acta Phys.Polon. B**39**, 2561 (2008).

LDRD BUDGET REQUEST BY FISCAL YEAR Physics Department Exploring signatures of saturation and universality in e+A collisions at eRHIC PI- R. Venugopalan				
COST ELEMENT	FISCAL YEAR 2010	FISCAL YEAR 2011	FISCAL YEAR 2012	Total Cost
Labor *				
Post Doc @80%	$ 25,389.50	$ 52,810.16	$ 27,461.28	$ 105,660.94
Fringe @ 28.00%	$ 7,109.06	$ 14,786.84	$ 7,689.16	$ 29,585.06
Salary: Physicist	$ -	$ -	$ -	$ -
Salary: Professional	$ -	$ -	$ -	$ -
Salary: Technician	$ -	$ -	$ -	$ -
Fringe @ 38.00%	$ -	$ -	$ -	$ -
Total Labor	$ 32,498.56	$ 67,597.00	$ 35,150.44	$ 135,246.01
Materials	$ 5,000.00	$ -	$ -	$ 5,000.00
Supplies-	$ -	$ -	$ -	$ -
Travel	$ 6,600.00	$ 6,600.00	$ 2,000.00	$ 15,200.00
				$ -
Total MST	$ 11,600.00	$ 6,600.00	$ 2,000.00	$ 20,200.00
Visitors- 10 conf. + 1 long term				
Per Diem esc @2%/yr	$ 6,137.00	$ 6,259.74	$ 10,260.00	$ 22,656.74
Housing esc @4%/yr	$ 7,020.00	$ 7,300.80	$ 9,720.00	$ 24,040.80
Car rental esc @4%/yr	$ 5,970.00	$ 6,208.80	$ 9,360.00	$ 21,538.80
R & D Sub contract student	$ 17,500.00	$ 30,600.00	$ 13,005.00	$ 61,105.00
Organizational Burden @ 12.60%	$ 4,094.82	$ 8,517.22	$ 4,428.96	$ 17,041.00
Electric Power @ 1.92%	$ 623.97	$ 1,297.86	$ 674.89	$ 2,596.72
ITD Allocation @ 3.4% of TMC	$ 2,148.58	$ 3,357.98	$ 2,212.33	$ 7,718.89

TOTAL DIRECT COST	$ 87,592.94	$ 137,739.41	$ 86,811.62	$ 312,143.96
G&A Burden	$ 6,657.23	$ 10,672.53	$ 6,287.70	$ 23,617.45
Common Support	$ 15,943.51	$ 24,917.76	$ 15,962.93	$ 56,824.20
Materials Burden @ 8.25%	$ 2,893.28	$ 3,581.23	$ 2,010.11	$ 8,484.61
TOTAL PROJECT COST	$ 113,086.94	$ 176,910.92	$ 111,072.36	$ 401,070.22

		FY 10 FTE	FY 11 FTE	FY 12 FTE	Total FTE's
TBD	Post Doc	0.43	0.85	0.43	1.70
TBD	Scienific	0.00	0.00	0.00	0.00
TBD	Scienific	0.00	0.00	0.00	0.00
TBD	Scientif	0.00	0.00	0.00	0.00
TBD	Scienific	0.00	0.00	0.00	0.00
TBD	Professional	0.00	0.85	0.00	0.85
TBD	Technical	0.00	0.00	0.00	0.00
Total FTE's		0.43	1.70	0.43	2.55
List all materials costing over $5000		None	None	None	None